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# Spin magnetic moment and persistent orbital currents in cylindrical nanolayer

N.G. Aghekyan [a], S.M. Amirkhanyan [a], E.M. Kazaryan [a], H.A. Sarkisyan [a,b,*]

[a] *Russian-Armenian (Slavonic) University, 123 H. Emin, Yerevan, Armenia*
[b] *Yerevan State University, 0025 Al. Manukyan, Yerevan, Armenia*

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ABSTRACT

Densities of persistent orbital and spin magnetic moment currents of an electron in a cylindrical nanolayer in the presence of external axial magnetic field are considered. For the mentioned current densities analytical expressions are obtained. The conditions when in the system only spin magnetic moment current is present are defined. Dependencies of orbital and spin magnetic moment currents on geometrical parameters of nanolayer are derived. It is shown that in the case of layered geometry the dependence of spin magnetic moment current on radial coordinate has a non-monotonic behavior and changes the sign. This is the peculiarity of layered geometry of nanostructure and it is due to the behavior of wave function of the system along the radial direction. Dependent on the directions of the field and orbital rotation of the electron there are defined values of radial coordinates when the orbital current disappears. The transition to the case of cylindrical quantum dot is discussed as well.



## 1. Introduction

The development of precise methods of the growth of semiconductor nanostructures makes possible the realization of zero-dimensional systems of various geometrical forms and sizes [1]. As we know quantum dots (QD) are those structures where quantum effects visualize themselves more

* Corresponding author at: Russian-Armenian (Slavonic) University, 123 H. Emin, Yerevan, Armenia. Tel.: +374 10250593.
*E-mail address:* shayk@ysu.am (H.A. Sarkisyan).

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vividly. Indeed, due to the full quantization of the spectrum of charge carriers, QDs have similar properties to real atoms, hence, usually, QDs are called "artificial atoms" [2]. They are considered to be very perspective systems that can be used as base elements for contemporary nanoelectronics: started from lasers based on QDs and finished with new generation solar cells [3–7]. The physical processes in QDs are being investigated intensively by the specialists, because besides the pure academic interest, the results of investigation can be applicable [8]. Currently spherical, cylindrical, ellipsoidal, pyramidal, lens-shaped and many other QDs are experimentally realized and thoroughly investigated [9–16]. All of these QDs listed above have specific geometries that impose their electronic, optical, kinetic and other characteristics. The latest circumstance gives a vast choice of properties of QDs for solving a concrete practical problem. An interesting class of QDs are layered QDs, for which there are two boundaries of transition from QD to the surrounding medium. This makes possible to control the physical properties of layered samples easily. In many papers it was considered electronic, optical and also thermal characteristics of ring-like and other layered nanostructures. The theoretical investigation of electron states in layered nanostructures is originated from the pioneering works of Chakraborty and Pietiläinen [17,18]. Authors have considered one-electron and many-electron states in quantum rings at the presence of impurities, as well as under the influence of a magnetic field. At the same time, taking into account that in the radial direction the movement of electron is restricted both on internal and external radiuses, Chakraborty and Pietiläinen have suggested a model of confining potential having the form of a two-dimensional shifted oscillator. In Ref. [19–21] the authors have discussed one and two electronic states in spherical nanolayer with different confinement potentials. Energy spectrum and wave functions have been obtained dependent on inner and outer radiuses. Along with changing inner or outer radiuses it is also possible to control physical properties of nanolayers with external electrical and magnetic fields, with hydrostatic pressure and so on. This means that it is urgent to study such systems by investigating interband and intraband absorption coefficients, ballistic conductance of orbital and spin currents. Particularly the problem of charge current in ring like structures was discussed in many papers. For example in Ref. [18] there have been studied the effect of electron-electron interaction on the magnetic moment (associated with the persistent current) of electrons in a quantum ring. There was introduced a model where the electron makes a circular motion in a parabolic confinement simulating a quantum ring which is subjected to a perpendicular magnetic field. The electron states in such a ring with and without the Coulomb interaction are then investigated. There also explored the limits of narrow and wide rings. In Ref. [22] it was demonstrated the theoretical possibility of obtaining a pure spin current in a 1D ring with spin-orbit interaction by irradiation with a non-adiabatic, two-component terahertz laser pulse, whose spatial asymmetry is reflected by an internal phase difference. In Ref. [23] the persistent current in two vertically coupled quantum rings containing few electrons is studied. It was shown that the Coulomb interaction between the rings in the absence of tunneling affects the persistent current in each ring and the ground-state configurations. Quantum tunneling between the rings alters significantly the ground state and the persistent current in the system. Also this problem is discussed in Refs. [17,24,25].

In general, the quantum mechanical expression for one electron current in presence of magnetic field with consideration of the spin of electron consists of two components. The first one characterizes the orbital current $\vec{j}_{Orb}$ and it is connected with orbital motion of the electron. The second one is caused by the magnetic moment of electron and it is called density of spin magnetic moment current – $\vec{j}_{SMM}$. As far as this current is not conditioned with directed motion of the electron, therefore, its divergence equals to zero:

$$div\,\vec{j}_{SMM} = 0.$$

This current is specific and its existence is and is caused by the presence of the spin magnetic moment of the electron. In Ref. [26] the peculiarities of spin magnetic moment current were discussed, particularly, when hydrogen atom electron is in and states. In these states, the total current is formed exclusively by the spin magnetic moment current of the electron. It is interesting to note, that similar problem arises also in optics. Particularly, in Ref. [27] it is shown that for scalar light, the current is the familiar expectation value of the intensity-weighted momentum operator. Current is distinct from the